International Journal of Mechanical and Production
Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 9, Issue 4, Aug 2019, 1055-1062

EXPERIMENTAL INVESTIGATION OF EXHAUST HEAT RECOVERY IN PETROL ENGINE USING NANO ENHANCED PCM

ADITYA S. PILLAI & D. SENTHILKUMAR*

Department of Mechanical Engineering, Amrita School of Engineering,

Amrita Vishwa Vidyapeetham, Coimbatore, India

ABSTRACT

About thirty percentage of the heat released during combustion process is carried away by the exhaust gas formed inside the internal combustion engine. This waste heat can be extracted through exhaust gas recirculation system, and can be utilized to do some useful work. In this experiment, waste heat from a multi-cylinder four-stroke petrol engine is recovered using a heat exchanger along with a thermal energy storage tank. Exhaust gases require larger area for better heat transfer since they have low surface convective heat transfer coefficient. So, a shell and tube heat exchanger is used to extract the sensible heat from the exhaust gas. Water flowing through this heat exchanger becomes the sensible heat storage medium. Latent heat from the exhaust gas is extracted through PCM contained in the thermal storage tank. Organic PCM like paraffin is one of the most commonly used material in thermal storage tank due to its thermal stability and non-corrosive properties. Paraffinis kept in cylindrical capsules within the thermal storage tank which is insulated with glass wool covered with aluminium cladding. Since thermal conductivity of paraffin is 0.24 W/mK to enhance its thermal properties, Aluminium oxide nanoparticles having thermal conductivity of 36 W/mK is added to it. Simple direct synthesis method is used for uniformly mixing Al_2O_3 nanoparticles with paraffin. 1.0 weight percentage of Al_2O_3 nanoparticles are dispersed in their paraffin medium by using an ultrasonicator. Experiments are conducted at half load condition and temperature variations are measured using a K-type thermocouple. First set of trials are done with only paraffin and the second set of trials are done with Al_2O_3 nanoparticle enhanced paraffin wax. The heat recovered from the exhaust gas, heat lost and energy saved etc is the parameters which are evaluated. Variation of temperature in the tank, charging efficiency, rate of charging and heat loss coefficient is calculated from the obtained values. From the results, it is observed that more charging efficiency and heat transfer rate is obtained in case of nano-enhanced PCM. Heat loss coefficient is also lower for nano enhanced PCM, hence it can be concluded that nano enhanced PCM is able to store heat energy for a longer duration.

KEYWORDS: Exhaust Gas Heat Recovery, Nano – Enhanced PCM & Heat Utilization Methods

Received: May 08, 2018; **Accepted:** May 28, 2019; **Published:** Jul 16, 2019; **Paper Id.:** IJMPERDAUG2019108

Original Article

INTRODUCTION

In an internal combustion engine, 30 % of the heat energy produced during combustion is carried away by the exhaust gases. Therefore, abundant scope is present in utilising this waste heat for productive purposes like air preheating, co generation, cooling etc. Engines having exhaust gas re-circulation [EGR] system shows better performance as compared to the conventional engines without EGR [1]. Heat energy present in the exhaust gases is in the form of both latent heat and sensible heat. The concept of thermal storage tank having various phase change material is developed to extract the latent heat from the exhaust gases, whereas a heat exchanger can be used to

extract the sensible heat [2].

Researches have been done to further improve the efficiency of the thermal storage tank. This can be done by enhancing the properties of the phase change material present in the thermal storage tank and by choosing the PCM suitable for particular applications. Organic PCM like paraffin is thermally stableand non- corrosive, whereas inorganic PCM like salt hydrates have high melting enthalpy and high density [3]. Organic PCM like paraffin is one of the most commonly used material in thermal storage tank. Thermal and cycling stability tests have been done on paraffin, and it is proved that paraffin is compatible for use up to 80^{o} C and will not degrade till 1200 cycles [4].

However, organic phase change materials have low thermal conductivity; therefore some other material with higher thermal conductivity needs to be added in this. Nano-materials have proved to be a promising option for improving the thermal properties of these organic phase change materials[5]. Experiments have shown that, carbon nanotubes and carbon nanofibers can improve the thermal conductivity of environment friendly PCM like soy wax [6]. Various nano-additives have different influences on heat conduction performance of the phase change material. Changes in concentration of the additives also have an impact on the characteristics influencing the thermal storage [7].

By extracting the heat properly from the exhaust gases, efficiency of the whole system can be improved. A combined system has a shell and tube heat exchanger with finned tubes, along with thermal energy storage tank having cylindrical capsules of PCM can extract 10-15% of the waste heat from exhaust gases [8]. This type of integrated systemhas shownenergy efficiency of 3 to 35% [9]. Experiments are also done with triangular finned shell and tube heat exchanger for storing the sensible heat, and copper oxide nanoparticles enhanced PCM for latent heat storage. Heat extraction rate of 4 to 5 % is obtained by using this system in full load condition of the engine. [10].

Thus, an integrated system with a heat exchanger for extracting the sensible heat and nanoparticle enhanced organic PCM like paraffin for extracting, latent heat can be efficiently utilised for exhaust gas heat recovery. Since thermal conductivity of paraffin is 0.24 W/mK, to enhance its thermal properties, Aluminium oxide nanoparticles having thermal conductivity of 36 W/mK is added to it. This integrated set up is used to recover heat energy from a multi cylinder petrol engine.

OBJECTIVE

To recover the exhaust waste heat coming out of the engine exhaust using a heat recovery heat exchanger and a Thermal Storage Tank. The heat will be stored inside the TES system using Nano-enhanced Phase change material.

EXPERIMENTAL SETUP

Engine with Heat Exchanger

A multi-cylinder, four-stroke, water cooled gasoline engine having bore of 85mm and stroke 92mm (Rated power 7.35 kW at 1500rpm) is used for the experimental work. It is connected to the electrical dynamometer and integrated with heat recovery HE. And, the exhaust gases have very low convective heat transfer coefficient. To have better heat transfer on gas side, larger area is required. Since, this requirement cannot be fulfilled by embedding heat exchanger inside the thermal storage tank; a separate heat exchanger is used. A shell and tube heat exchanger is used for heat recovery from the exhaust stream. The exhaust heat is passed through the shell and water, which is sensible heat storage medium, is circulated through the tubes. Heat transfer medium is water. The shell is made up of mild steel and tube of cooper.

Figure 1: Multi Cylinder Petrol Engine

Figure 2: Heat Recovery Heat Exchanger

Thermal Energy Storage Tank

Since PCM is having very low thermal conductivity, due to which the resistance for heat transfer is varied, PCM can't be stored separately inside the TES tank. Hence, Nano particle PCMs are packed inside cylindrical capsules. TES tank is made up of stainless steel and has inner diameter 240mm and height 250mm. It consists of paraffin as the latent heat storage medium and water as sensible heat storage medium. Paraffin is encapsulated inside cylindrical steel containers of 80mm diameter and 100mm height. Thermal storage tank consists of 1.2kg paraffin filled in 3 containers and 6.979 kg water as heat transfer fluid (HTF). 400g of paraffin is stored inside each cylindrical container. Thermal characteristics of paraffin are listed in the table. The containers are kept over a stand having wired mesh across the surface. TES is insulated using glass wool.

Temperatures at various points inside and outside storage tank are recorded using k-type thermocouples. Temperature indicator device is used to note down the temperatures obtained at various locations. U-tube manometer is used to determine the mass flow rate of air at the inlet of engine.

Figure 3: TES Tank with PCM Containers

Figure 4: TES Tank with Insulation

Preparation of Nano Enhanced Phase Change Material (NEPCM) Mixture

Paraffin at room temperature is at solid state. To add the Al_2O_3 Nano particle to the paraffin, it is heated to change from solid to liquid state. Paraffin is heated using electromagnetic stirrer at 100°C for the duration of 10 minutes.

The paraffin solution is then blend at 120°C for 30 minutes for attaining uniformity. The mixing of alumina and paraffin is done using direct-synthesis method. Alumina is added to paraffin uniformly until desired concentration was achieved. The additives were dispersed in paraffin with weight fraction of 1.0%. The liquid Nano enhanced PCM is continuously stirred using the electromagnetic stirrer at 1500 rpm for 45 minutes at 120°C to achieve homogeneous distribution of particles. The synthesis of NEPCM is completed when mixture is dissolved at 80°C for 1 hour using ultrasonic bath. The melted NEPCMs were poured into cylindrical vessels and allowed to cool.

METHODOLOGY

Experiment 1

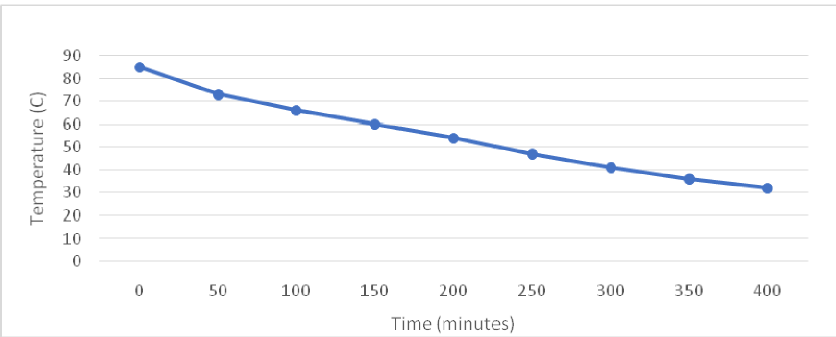
The experiment is done under half load condition. Initially, carbon deposition on tube surface can be found. To avoid this condition, the exhaust gas is not allowed to flow through heat exchanger. After 15 mins, the exhaust gas is allowed to flow through the HRHE. The engine is then kept running at half load condition for 25 minutes to attain stabilized temperature at the outlet of heat exchanger. Rated speed of 1500rpm is maintained throughout the experiment, which is measured using a tachometer. Water at the temperature of 85˚C is obtained at the outlet of heat exchanger and is stored in the thermal storage tank containing only paraffin as the phase change material (PCM). Heat transfer from the hot fluid takes place for a charging time of 80 minutes. The temperature of water and thermal storage tank is observed for the charging period. Charging rate and charging efficiencies are also calculated. Heat stored inside the thermal storage tank is determined

Experiment 2

The experiment is done under half load condition. Initially, carbon deposition on tube surface can be found. To avoid this condition, the exhaust gas is not allowed to flow through heat exchanger. The engine is then kept running at half load condition for 25 minutes to attain stabilized temperature at the outlet of heat exchanger. In this experiment, Nano particle enhanced paraffin is used for storing the heat. Nano particle used here is alumina (Al_2O_3). Mixture of alumina and paraffin is done using direct synthesis method. Electromagnetic stirrer and ultrasonic bath were used to mix the materials and attain homogeneous mixture. 1.0% by weight of alumina is added to 1.2 kg of paraffin. Water at the temperature of 85˚C, which is obtained at the outlet of heat exchanger, stored in the thermal storage tank containing Al_2O_3 enhanced paraffin as the phase change material. The procedure followed in this experiment is same as the experiment 1. Charging rate, charging efficiency, heat stored in thermal energy storage tank and heat loss coefficient is calculated.

RESULTS AND DISCUSSIONS

Variation of Temperature in TES Tank



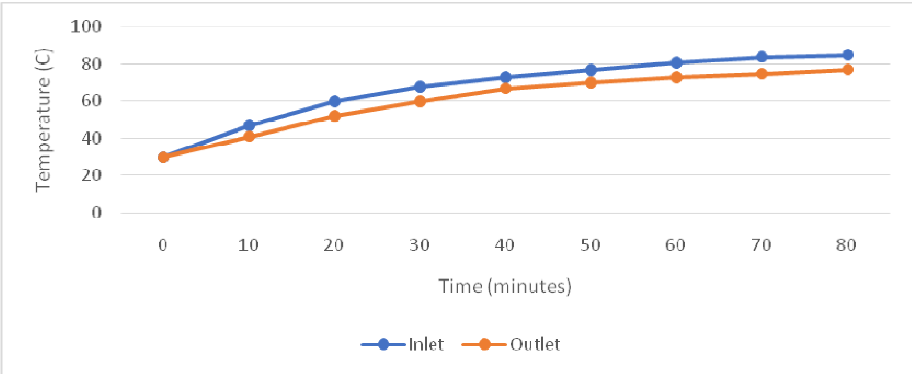
Graph 1: Variation of Temperature is TES Tank

The graph 1 shows the decrease in temperature inside the Thermal Storage Tank filled with water, which is at 85˚C. This shows that the insulation done around the tank was good enough to keep the heat inside the tank for long period of time.

Heat Loss Coefficient

$m_w C_{pw} (T_1 - T_2) = h_L * A_s * LMTD / t_1$

$h_L = 11.007\ W/m^2K$



Graph 2: Water Temperature at Inlet and Outlet of TES Having Nano-Enhanced PCM

Initially, when the engine is not started, the inlet and outlet of the tank is at same temperature. Gradually, when the exhaust heat is passed into the tank, the temperature at the inlet increases and is higher than the temperature at outlet of tank. This shows that the heat is getting stored inside the tank by the nano-enhanced phase change material.

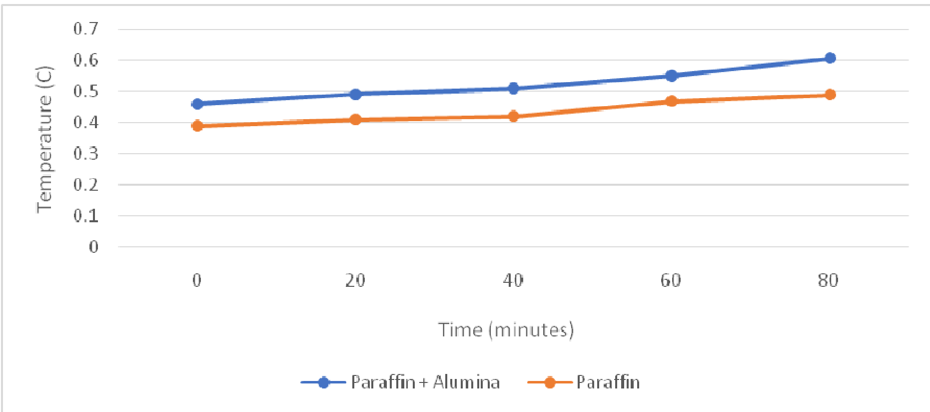
Rate of Charging

At a particular load, the heat energy supplied to the TES tank is calculated and its average rate is considered as the rate of charging. It is determined by the ratio of total heat stored to the time of charging.

$Qc = [m_w * C_{pw} * (T_f - T_i) + m_p * C_{pp} * (T_f - T_i) + m_p L]/t$

With paraffin: Qc = 0.56 kW

With Al_2O_3 enhanced paraffin: Qc = 0.606 kW



Graph 3: Rate of Charging in TES Tank

From graph 3, it can be seen that the charging rate increases with the addition of Alumina into the phase change material paraffin, as compared to pure paraffin. The charging rate increases from 0.56kW to 0.606kW when alumina was added to the paraffin.

Charging Efficiency

It is defined as the ratio of charging rate and the average heat extraction rate:

$\eta c = Qc/Qe$

The charging efficiency obtained when only paraffin was used is 57.04%. Whereas, when alumina nano material was added to paraffin, the efficiency gets increased to 60.05%.

CONCLUSIONS

In this paper, experiments are conducted on multi cylinder petrol engine integrated with shell and tube heat exchanger and thermal storage system consisting of water as sensible heat storage medium. Nano-enhanced paraffin is used as latent heat storage medium within the cylindrical capsules kept inside the TES tank. By comparing the results obtained from simple paraffin and Al_2O_3nano powder enhanced paraffin, it is observed that more charging efficiency and heat transfer rate is obtained in case of nano-enhanced PCM. Heat loss coefficient is also lower for nano enhanced PCM, hence it can be observed that nano enhanced PCM is able to store heat energy for a longer duration. It is also concluded that even better thermal performance system could be obtained by using better insulation.

NOMENCLATURE

Cp_w – specific heat at constant pressure, [J/kg °C]

$\dot{m}$ – mass flow rate, [kg/s]

Q – heat extraction rate, [kW]

TES – thermal energy storage

HRHE – Heat Recovery Heat Exchanger

PCM – phase change material

NEPCM – nano-enhanced phase change material

REFERENCES

1. *S.P.Subramanian, V.Pandiyarajan, "Experimental analysis of PCM based IC engine exhaust waste heat recovery system" Applied Energy 88 (2004) 77- 87.*

2. *Belen Zalba, Jose M Marin, Luisa F Cabeza, "Review on thermal energy storage with phase change: materials, heat transfer analysis and applications"; Applied Thermal Engineering 23 (2003) 251–283.*

3. *Lavinia Gabriela" Thermal Energy Storage with Phase Change Material", Leonardo Electronic Journal of Practices and Technologies, issue 20, January-June 2012 p. 75-98.*

4. *JaumeGasia, Laia Miró, Alvaro de Gracia, Camila Barreneche ,Luisa F. Cabeza, "Experimental Evaluation of a Paraffin as Phase Change Material for Thermal Energy Storage in Laboratory Equipment and in a Shell-and-Tube Heat Exchanger" Applied Sciences. 2016, 6, 112.*

5. *R.K Sharma , Tyagi H, Ganesan V.V, Meteselaar S, C.Sandaran "Developments in organic solid-liquid phase change materials and their applications in thermal energy storage" ; Energy Conversion and Managemanet95 (2015) 193–228*

6. *Yanbin Cui, Caihong Liu, Shan Hu, Xun Yu, " The experimental exploration carbon nanofiber and carbon nano tube additives on thermal behavior of phase change material"; Solar energy materials and Solar cells 95(2011)1208-1212.*

7. *Tun-Ping Teng* and Chao-Chieh Yu "Characteristics of phase-change materials containing oxide nano-additives for thermal storage" Nanoscale Research Letters 2012, 7:611.*

8. *V. Pandiyarajana, M. ChinnaPandianb, E. Malana, R. Velraja, R.V. Seeniraja; "Experimental investigation on heat recovery from diesel engine exhaust using finned shell and tube heat exchanger and thermal storage system", Applied Energy 88 (2011) 77–87*

9. *K.Nantha Gopal, Rayapati Subbarao, V.Pandiyarajan and R. Velraj, "Thermodynamic Analysis of a Diesel Engine Integrated with a PCM Based Energy Storage System" Int. J. of Thermodynamics(2010) Vol. 13 (No. 1), pp. 15-21*

10. *Maria Robert, Abhishek Kumar Singh ,Wilson John, Lalgudi Ramachandran ganapathysubramanianand Abhinay Kumar Singh, "Waste heat recovery from diesel engine using custom designed heat exchanger and thermal storage system with nanoenhanced phase change material"; Year 2017, Vol. 21, No. 1B, pp. 715-727*

11. *Thakrele, M. H. (2014). Experimental study on foam concrete. International journal of Civil Structure Environment Infrastructure Engineering Research and development (IJCSEIERD), 4(1-2014), 145-158.*

12. *J. S. Jadhao, D. G. Thombare, "Review on Exhaust Gas Heat Recovery for I.C. Engine" International Journal of Engineering and Innovative Technology (IJEIT) (2013), Volume 2, Issue 12, pp 93-100.*

13. *Sangki Park, Seungchul Woo, Jungwook Shun, KihyungLi , " Experimental study on heat storage system using phase-change material in a diesel engine" , Energy (2016) pp 1- 11.*

14. *Kim KB, Choi KW, Kim YJ, Lee KH, Lee KS. "Feasibility study on a novel cooling technique using a phase change material in an automotive engine." Energy 2010; 35:478–84*

15. *Srivatsan Sampath, J. B Anand, S Deepak, D Senthil Kumar, "Experimental Analysis of Heat Sinks incorporating Phase Change Materials and Thermal Conductivity Enhancers" International Journal of Engineering Research & Technology (IJERT),ISSN 2278-0181 Vol 3 Issue 5 ,May 2014*

16. *Sandesh Bhaskar, Waqar Katib Ahmed and D.Senthilkumar, "Investigation of Phase Change Material as a Potential Replacement of EGR Cooler" Applied Mechanics and Materials Vol. 798 (2015) pp 200-204.*

17. *Siddhartha Prabhakar.N, D.Senthil Kumar "Study on Performance and Emission Characteristics of a Diesel Engine by Preheating the Intake Air through Exhaust Heat Recovery" "International Journal of Applied Engineering Research. Vol 10, No. 85 (2015).*